CLAIMS

What is claimed is:

1. A method for determining a physical parameter of features on a substrate, said method comprising:
   a) illuminating said substrate with an incident light having an incident wavelength range $\Delta\lambda$ within which said substrate is at least semi-transparent such that said incident light enters said substrate and said features;
   b) receiving a response light from said substrate and said features;
   c) measuring a response spectrum of said response light;
   d) computing a complex-valued response due to said features and said substrate;
   e) determining said physical parameter from said response spectrum and said complex-valued response.

2. The method of claim 1, wherein said complex-valued response comprises at least one response selected from the group consisting of complex reflectance amplitude and complex transmittance amplitude and said response spectrum comprises at least one response spectrum selected from the group consisting of reflectance R and transmittance T.

3. The method of claim 2, wherein said at least one complex-valued response is a complex reflectance amplitude and said method further comprises computing said reflectance R by multiplying said complex reflectance amplitude with its complex conjugate.

4. The method of claim 2, wherein said at least one complex-valued response is a complex transmittance amplitude and said method further comprises computing said transmittance T by multiplying said complex transmittance amplitude with its complex conjugate.

5. The method of claim 1, wherein said incident light has a vertical coherence length L_{vc} sufficiently small with respect to a thickness d_s of said substrate to produce incoherence in said response light.

6. The method of claim 5, further comprising averaging a phase δ_s of said complex-valued response.

7. The method of claim 1, wherein said incident wavelength range $\Delta\lambda$ is selected such that said features produce a coherent fraction β and an incoherent fraction $(1-\beta)$ in said response light.

8. The method of claim 7, further comprising determining said coherent fraction β from a lateral coherence length L_{1c} of said incident light.

9. The method of claim 1, wherein said features are periodic and said incident light is focused to an illumination area covering a sufficiently small number of said features such that diffraction effects are negligible.

10. The method of claim 1, wherein an area of said features is larger than a lateral coherence length L_{lc} of said incident light and said method comprises incoherently adding said complex-valued response from said features.

11. The method of claim 1, wherein an area of at least one of said features is smaller than a lateral coherence length L_{lc} of said incident light and said method comprises coherently adding said complex-valued response from said features.

12. The method of claim 11, wherein said features comprise adjacent features made of a material 1 and covering a first area fraction a_1 illuminated by said incident light and of a material 2 covering a second area fraction a_2 illuminated by said incident light, and wherein coherently adding said complex-valued response comprises coherently adding at least one complex-valued response selected from the group consisting of a total complex-valued reflectance amplitude r_C and a total complex-valued transmittance amplitude t_C.

13. The method of claim 12, wherein said total complex-valued reflectance amplitude r_C is computed as:

$$r_C = a_1 r_1 + a_2 r_2,$$

and said total complex-valued transmittance amplitude t_C is computed as:

$t_C = a_1 t_1 + a_2 t_2$,

and where $a_1 + a_2 = 1$.

14. The method of claim 12, wherein said response spectrum comprises at least one response spectrum selected from the group consisting of a coherent reflectance R_C and a coherent transmittance T_C.

15. The method of claim 14, wherein said coherent reflectance R_C is calculated by using a cross term:

$$\langle r_1 \cdot r_2^* \rangle = \frac{r_{1,as} r_{2,as}^* + \left(t_{1,as} t_{2,as}^* t_{1,sa} t_{2,sa}^* - r_{1,as} r_{2,as}^* r_{2,sa} r_{2,sa}^* \right) r_{1,sb} r_{2,sb}^* e^{-2\alpha_s d_s}}{1 - r_{1,sa} r_{2,sa}^* r_{1,sb} r_{2,sb}^* e^{-2\alpha_s d_s}},$$

where α_s is an absorption coefficient of said substrate and d_s is a thickness of said substrate.

16. The method of claim 15, wherein said incident light is focused on a back side of said substrate and said cross term is computed as

$$\langle r_1 \cdot r_2^* \rangle = t_{1,as} t_{2,as}^* t_{1,sa} t_{2,sa}^* r_{1,sb} r_{2,sb}^* e^{-2\alpha_s d_s}.$$

17. The method of claim 14, wherein said coherent transmittance T_C is calculated by using a cross term:

$$\left\langle t_1 \cdot t_2^* \right\rangle = \frac{t_{1,as} t_{2,as}^* t_{1,sb} t_{2,sb}^* e^{-\alpha_s d_s}}{1 - r_{1,sa} r_{2,sa}^* r_{1,sb} r_{2,sb}^* e^{-2\alpha_s d_s}} = Ae^{i\phi},$$

where A is the amplitude of $\left\langle t_1 \cdot t_2^* \right\rangle$, ϕ is the phase shift between t_1 and t_2, α_s is an absorption coefficient of said substrate and d_s is a thickness of said substrate.

18. The method of claim 1, further comprising collimating said incident light.

19. The method of claim 1, further comprising focusing said incident light.

20. The method of claim 19, wherein said incident light is focused on a surface of said substrate.

21. The method of claim 1, wherein said physical parameter is selected from the group consisting of depth, width, real part of the complex refractive index, imaginary part of the complex refractive index.

22. The method of claim 1, further comprising computing a phase shift δ in said complex-valued response.

23. The method of claim 1, wherein said at least one feature is positioned on a first side of said substrate and said method comprises illuminating said substrate from a side

opposite said first side and focusing said incident light.

24. The method of claim 1, wherein said at least one feature is positioned on a first side of said substrate and said method comprises illuminating said substrate with said incident light from said first side.

25. The method of claim 1, wherein said physical parameter is derived from a phase shift ϕ in said response light.

26. The method of claim 25, wherein said response light is transmitted such that:

$$\phi = \phi_T = \frac{2\pi(n\cos\theta_2 - \cos\theta_1)t_s}{\lambda}.$$

27. The method of claim 25, wherein said response light is reflected such that:

$$\phi = \phi_R = \frac{4\pi n t_s \cos\theta_2}{\lambda}$$

28. The method of claim 1, wherein said features comprise at least one film deposited on said substrate.

29. The method of claim 28, wherein said features comprise at least one embedded feature in said at least one film.

30. An apparatus for determining a physical parameter of features on a substrate, said apparatus comprising:

a) an illumination source for producing an incident light having an incident wavelength range $\Delta\lambda$ within which said substrate is at least semi-transparent;

b) optics for guiding said incident light such that said incident light enters said substrate and said features;

c) a detector for receiving a response light from said substrate and said features and measuring a measured response spectrum of said response light;

d) a processing unit for computing a complex-valued response of said features and said substrate and for determining said physical parameter from said measured response spectrum and said complex-valued response.

31. The apparatus of claim 30, wherein said substrate is transparent within said incident wavelength range $\Delta\lambda$.

32. The apparatus of claim 30, wherein said substrate is optically thick.

33. The apparatus of claim 30, wherein said illumination source is broadband and said incident wavelength range $\Delta\lambda$ extends from about 190 nm to about 1000 nm.

34. The apparatus of claim 30, wherein at least one of said features comprises a metal layer.